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Modelling and Simulation of the Cement Clinker Burning Process

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Keywords:
industrial processes, dynamic, object-oriented, interactive simulation, training

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manufacturer of cement production plants. The developed simulation framework is extendable and arbitrary plant configurations
can be described due to an object-oriented modeling concept. Thus the continuously increasing process-know-how can be
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interactive simulator for simple training purposes, that in the future might be used for further applications. This demands the
extension and optimisation of the model and suitable parameter values and initial starting values.

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Veranstaltungskalender 2000

Januar

4-7 Jan:
33rd Hawaii International Conterence on System Sciences (HICSS-33) - The Software Technology Track. Maui, Hawaii. http://cs.unomaha.edu/~rewini/SWT-CFP.html

10-12 Jan:
HPCA-6, Sixth Int'l Symp.on High-Performance Computer Architecture, Toulouse, Grance. Contact Josep Torellas, torella@cs.uiuc.edu. See http://www.irit.fr/HPCA6.

25-27 Jan:
Multimedia Computing and Networking 2000 (MMCN00). San Jose, California. http://cairo.cs.uiuc.edu/mmcn/.

Februar

2-4 Feb:
3rd MATHMOD. International Symposium on Mathematical Modelling. Vienna, Austria; Contact: Prof. Dr. Inge Troch, Technische Universität Wien, Wiedner Hauptstrasse 8-10, A-1040 Wien, Tel.: +43-1-58801-11451, Fax: +43-1-58801-11499, email: inge.troch@tuwien.ac.at, WWW: http://simtech.tuwien.ac.at/3rdMATHMOD/

20-22 Feb:
IPCCC 2000, Int'l Performance, Computing, & Comm. Conf., Phoenix, Ariz. Contact Jagan Agrawal CS and Telecommunications Dept., Univ. of Missouri, 5100 Rockhill Rd., Kansas City, MO 64110; agrawal@cstp.umkc.edu. See http://ipccc.org/ipccc2000/.

21-22 Feb:
ASIM-STS'2000. Meeting ASDIM-FG "Simulation Technischer Systeme". Esslingen, Germany; Contact: Prof. Dr. Ing. Gerald Kampe, FHT Esslingen, Flandernstraße 101, D-73732 Esslingen, Tel.: +49-711-397-4221, Fax: +49-711-397-4212, email: gerald.kampe@fht-esslingen.de

März

5-8 März:
The Fifth INFORMS Telecommunications Conference (Boca-2000). Sheraton Boca Raton Hotel, Boca Raton, Florida. http://www.crt.umontreal.ca/GERAD/boca2000/

9-12 März:
8th International Conference on Telecommunication Systems, Modeling and Analysis. Nashwill, Tennessee, USA. http://munin.utdallas.edu/atsma/icts/icts2000.html.

26. März:
Gigabit Networking Workshop GBN 2000 (joint with INFOCOM '2000). Tel Aviv, Israel. http://www.ccrc.wustl.edu/pub/ieee-tcgn/conference/gbn2000.

26-27 März:
The Third IEEE Conference on Open Architectures and Network Programming, (OPENARCH 2000 - Joint with INFOCOM '2000), Tel Aviv, Israel. http://comet.columbia.edu/activities/openarch2000

26-30 März:
IEEE INFOCOM '2000. Dan Panorama Hotel, Tel Aviv, Israel. http://www.comnet.technion.ac.il/infocom2000. http://www.cse.ucsc.edu/~rom/infocom2000. htto://halo.kuamp.kyoto-u.ac.jp/~infocom.

April

10-14 Apr:
NOMS'2000 - IEEE/IFIP Network Operations And Management Symposium. Hilton Hawaiian Village, Honolulu,

Hawaii, USA. http://www.nomsorg/2000/.

Mai

1-2 Mai:
PACKET VIDEO 2000. The 10th International Packet Video Workshop. Forte Village Resort, Cagliari, Italy. http://www.diee.unica.it/pv2000/

2-3 Mai:
Workshop: Agent Based Simulation. Passau, Germany; Contact: WWW: http://www.or.uni-passau.de/workshop2000/

2-4 Mai:
MOSIS 2000. 34th Int. Conference on Modelling and Simulation of Systems. Roznov pod Radhostem, Czech Republik; Contact: Jan Stefan, FEI-VSB TU, Ostrava, tr. 17. Listopadu 15, CZ-70833 Ostrava Poruba, email: jan.stefan@vsb.cz, WWW: http://www.fee.vutbr.cz/UIVT/ism/

8-10 Mai:
EUROMEDIA 2000. Antwerp. Bergium; Contact: Philippe Geril, SCS Europe, c/o University of Ghent, Coupure Links 653, B-9000 Ghent, Tel.: +32-9 233 77 90, Fax: +32-9 223 49 41, email: Philippe.Geril@rug.ac.be, WWW: http://hobbes.rug.ac.be/~scs/conf/euromed2000/

14-19 Mai:
Networking 2000, IFIP-TC6 Conference. Paris, France. url: http://www.noc.uoa.gr/net2000/.

23-26 Mai:
ESM 2000. 14th European Simulation Multiconfernce. Ghent. Belgium; Contact: Phillipe Geril, SCS European Simulation Office, University of Ghent, Coupure Links 653, B-9000 Ghent, Tel.: +32-9 233 77 90, email: Philippe.Geril@rug.ac.be, WWW: http://hobbes.rug.ac.be/~scs/

28-31 Mai:
PADS 2000. 14th Workshop on Parallel and Distributed Simulation. Bologna, Italy; Contact: David Bruce, Defence Evaluation and Research Agency, St. Andrews Road, UK-Malvern WR14 3 PS, Tel.: +44-4684 895112, Fax: +44-1684 894389, email: dib@dera.gov.uk, WWW: www.dcs.exeter.ac.uk/~pads2000/

September

12-14 Sept:
ASIS 2000. 22nd Intl. Workshop Advanced Simulation Systems. Czech republic; Contact: Jan Stefan, FEI-VSB TU, Ostrava, tr. 17. Listopadu, CZ-70833 Ostrava Poruba, email: Jan.Stefan@vsb.cz

18-20 Sept:
ASIM/ESS'2000. 14. Symposium Simulationstechnik together with European Simulation Symposium. Hamburg, Germany; Contact: Prof. Dr. Dietmar P.F. Möller, Universität Hamburg, Inst. f. Informatik, Vogt-Kölln-Strasse 30, D-22527 Hamburg, Fax: +49-40-5494 2206, email: dietmar.moeller@informatik.uni-hamburg.de

20-22 Sept:
ESS'2000. European Simulation Symposium. Hamburg, Germany; Contact: Philippe Geril, SCS Europe, c/o University of Ghent, Coupure Links 653, B-9000 Ghent, Tel.: +32-9 233 77 90, Fax: +32-9 223 49 41, email: Philippe.Geril@rug.ac.be, WWW: http://hobbes.rug.ac.be/~scs/

Oktober

6-8 Okt:
MMT'99, 1999 Workshop on Multiaccess Mobility and Teletraffic for Wireless. Scuola Grande di San Giovanni Evangelist, Venice, Italy. http://mimobili.cselt.it/MMT99/.

MODELLING AND SIMULATION OF THE CEMENT CLINKER BURNING PROCESS

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KEYWORDS
Industrial processes, dynamic, object-oriented, interactive simulation, training

ABSTRACT

The cement clinker burning process is an extremely complex dynamical process, which currently is just fairly understood. A new wholistic approach for modelling and simulating of the process was made in co-operation with an experienced manufacturer of cement production plants. The developed simulation framework is extendable and arbitrary plant configurations can be described due to an object-oriented modeling concept. Thus the continuously increasing process-know-how can be incorporated in an evolutionary way. The simulation framework was implemented with the Dymola simulation system. Plant components are represented by modules accompanied by a visual representation. A process model generated by Dymola was then connected to an existing process automation system of cement plants by using a message passing system. The result is an interactive simulator for simple training purposes, that in the future might be used for further applications. This demands the extension and optimisation of the model and suitable parameter values and initial starting values.

INTRODUCTION

As opposed to many other industrial processes (like most chemical production plants and power plants) detailed and validated mathematical models are still missing for the cement production process. Despite its economical importance so far only a few steady-state models were developed for some parts of the whole system (Fig. 1) and the basics of the thermodynamical, chemical and mechanical processes taking place.

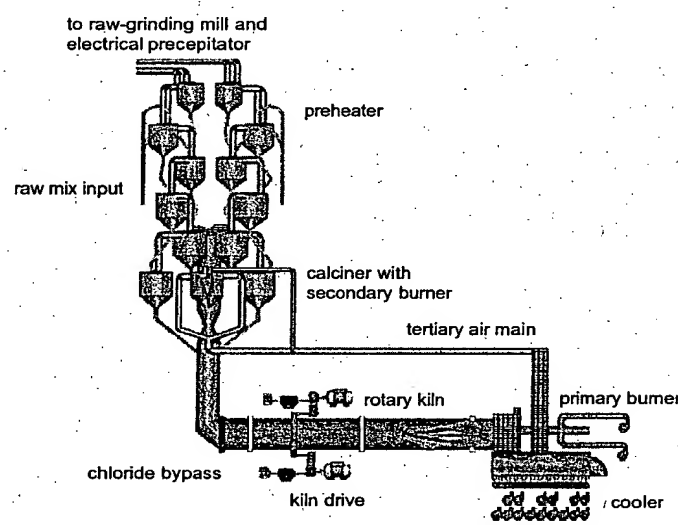

Fig. 1: Cement production plants are complex processes containing many separate units.

One reason for this lack of models might be the enormous number of chemical components involved in that high-temperature, multiple phase system. Moreover the process inputs, i.e. raw materials and fuels, are not well defined and inhomogeneous. These elements continuously enter the process and undergo many, even today just fairly known chemical transformations which depend on temperature, solid and gas velocities and flow, pressure, the existence of reactives, reaction time etc. The burning and material transformation processes happen sequentially and/or parallel in the same and/or different parts of the cement plant (Fig. 2). The dynamical system is

mostly not in a thermodynamical equilibrium or steady-state.
Despite these problems the more and more restrictive plant operation conditions with respect to energy consumption, environmental protection and quality insurance on the one hand and process control, plant design and control or training of personnel on the other hand, lead to a rapidly increasing demand for modelling and simulation. Some first attempts to simulate the process dynamically have been made, but the used models either include no detailed chemical reaction kinetics or are based on one fixed plant design (KHD 1999).

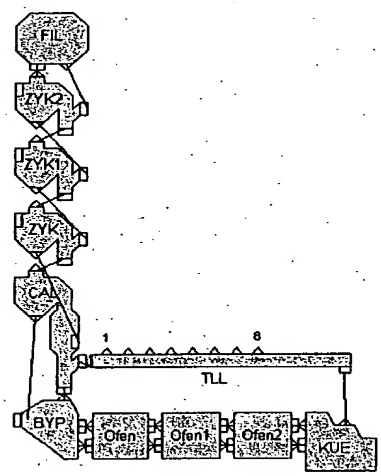

Fig. 2: Using the Dymola simulation framework an object-oriented implementation of the different units of a cement plant was realised.

THE CEMENT PRODUCTION PROCESS

After mining, crushing and prehomogenizing in blending beds the raw materials are proportioned, ground and dried in large ball or roller mills (VDZ 2000). Further homogenizing in large capacity silos takes place before the raw meal is conveyed to the preheater. In this cyclone cascade the meal is heated up and dried by the counter-flowing hot kiln exhaust gas. The decomposition of limestone into CaO and CO_2, i.e. calcining, happens mainly in the calciner, an at the bottom of the preheater installed burning chamber.
The heart piece of a cement production plant is represented by a rotary kiln in which sintering of the material takes place. At temperatures of about 1500 degrees Centigrade CaO fusions with SiO_2, Al_2O_3 and Fe_2O_3 to new granular compounds, the cement clinker. The heat of this main component of cement is nearly completely recovered in the clinker cooler.
After adding gypsum and other extra materials the clinker finally becomes fine ground and the product is stored as cement. Because of the counter-current operation and various bypass-modules, e.g. the tertiary air main from the cooler to the calciner, several gas cycles occur. Because the gas is always containing meal, ashes and fuels, cycles of solid materials also emerge.

TARGET DEFINITION

As a medium-term target for the development of a cement plant simulator the training of plant operators is a reachable goal (Klein 1999), because in this case the plant behaviour must only be qualitatively reproduced. However with increasing process-know-how this simulator should be extendable to be used for further applications, up to being used for plant development and design. This makes an evolutionary framework of modelling and simulation necessary. Moreover the simulator might be helpful finding answers on today's questions like how to effectively reduce emissions of SO_2, NO_x and heavy metals or the influence of wastes as a replacement for traditional fuels and raw materials.
In cooperation with Krupp Polysius, a world wide operating manufacturer of cement production plants, such a universal concept for modelling and simulation of the cement clinker burning process was developed. A first prototype of the extendable simulator was connected to a process control system for cement plants (Urbanke 2000). Simple simulations for training purposes are already possible.

DEMANDS AND METHODS

This contribution mainly deals with the object-oriented system modelling concept and the connection of the simulator to the process control system.

Modelling Concept

While choosing a suitable software-tool for modelling and simulation, the following demands had to be considered:

1. The separate units of the entire process should be organised in a module library. By the flexible coupling of modules the entire plant should be assembled.
2. Without having to redesign the whole system, the mathematical models within the single modules should be, as a part of the evolutionary method, changeable and extendable.
3. Dynamic and quasi-steady-state models of the process components must be mixed in one plant model.
4. A visualisation tool for the description of different plant configurations should be available.
5. In order to use the simulator for training purposes it should be connectable to the process control system.

Taking these points into account, the object-oriented modelling and simulation tool DYMOLA (Cellier et al. 1995) was used for implementation of the module library. In recent years, Dymola mainly was used for modelling of multidisciplinary systems in the fields of mechatronics or hydraulics. Therefore little experience in using this tool for simulating process technologies is existing. As soon as the simulator is running stable the model shall be transformed to the successor tool Modelica (Otter 1997).

To fulfil the demand for extendibility of the models the module interfaces were standardised, so that there is one type of connections for gaseous and one type for solid streams. The gaseous streams consist of 69 components, whereas a solid stream has 52 elements (Fig. 3). Thus when connecting two modules 138 respectively 104 process variables are linked. The number of components may later on be increased.
Component models were developed and implemented for exhaust filters, cyclones, calciners, the tertiary air main, bypass, different kiln regions and the clinker cooler. Corresponding to the great number of components in the gaseous and solid phases many mathematical equations had to be implemented in every module. The processes taking place within the modules are mainly described by mass and enthalpy balances.

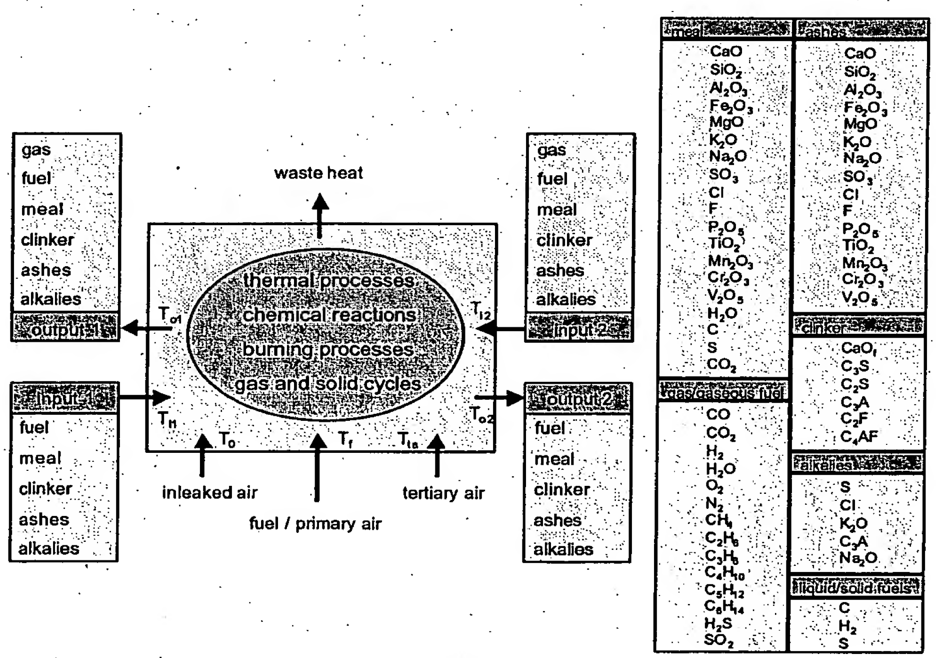

Fig. 3: Process modules are linked by two possible types of connections.

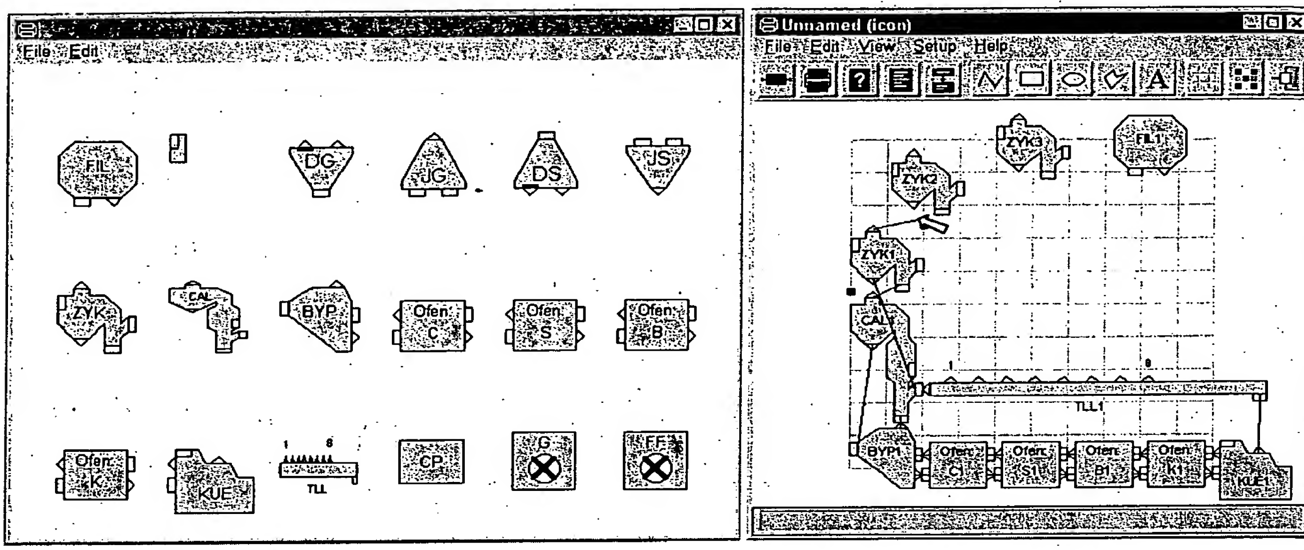

Fig. 4: Arbitrary system configurations can be assembled by drag & drop, using modules from the library.

Since only inadequate detailed knowledge about many chemical and thermodynamical processes is available at present, the temperature dependent kinetics of those reactions are substituted by rather raw mathematical approximations. Burning processes are defined in a separate module, which might be imported in those modules where burning of gaseous, liquid and solid fuels takes place.
All modules are organized and visualized in a graphical library. With the modelling tool Dymo-Draw their linking to an arbitrary system configuration is easily possible by drag & drop (Fig. 4).
In this early stage of process modelling many of the chemical components and their detailed behaviour could not be considered in every module. Thus a great number of trivial equations result when creating a complete system or model. These equations are mostly eliminated by Dymola with the means of symbolic manipulations. Nevertheless a complete model of even a small plant contains more than 200 differential and about 6000 algebraic equations.
Several non-linear algebraic loops occur because of the existence of material cycles and non-linear relations. With the integrated tearing-algorithm of Dymola (Elmqvist and Otter 1994) these loops are transformed to iterations with up to 20 variables. Developing such sophisticated models always includes the risk of errors in the models, typed equations or numerical algorithms. To reduce that risk the models were step-by-step designed and tested:

1. The mass and enthalpy balances were checked by redundant equations in every module.
2. The qualitatively right behaviour of every module was checked by simulating them separately with individual input-values.
3. Dymola automatically checks, if the system of equations is well determined, i.e. that every variable is solved by exactly one equation.

Nevertheless the first calculations ran into numerical problems, because the algebraic loops could not be consistently solved. Reasons for this are either a still inconsistent model or a lack of numerical stability of the implemented algorithm for solving such non-linear systems of equations.
To reduce the number and size of algebraic loops storage variables were included in the involved modules. Additionally some of the non-linear, temperature dependent relations were simplified. The remaining loops with up to 4 iteration variables are solved successfully and simulation runs can be carried out. After tuning the initial values and some system parameters the qualitatively proper simulation of even complex plants is now possible.

Connecting Of Simulator And Process

In order to obtain a realistic simulation environment for the training of plant operators, the simu-

lator has been directly connected to the process automation system of Krupp Polysius (Fig. 5). Although Dymola supports DDE, this method was rejected because of its unsure future development and its known susceptibility to failures. Instead the realisation of the process interface was done directly in C-code. To this end the C-function created by Dymola which contains the complete plant model, is directly called.
Process control and simulation are done on separate computers. The control of the simulation is done by using a message passing system, which is already implemented in the process control system. The process input parameters are transmitted from the plant's pulpit to the simulator and the calculated virtual measurement values are transmitted back to the control system. The interface structure allows to implement new models of any kind of plant configuration.

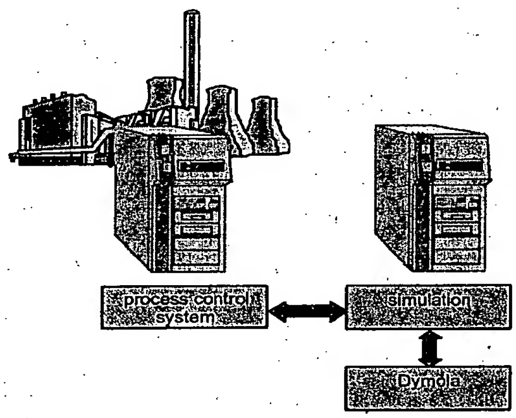

Fig. 5: Bidirectional coupling of process control and simulation system by using message passing.

RESULTS AND OUTLOOK

Prototypical simulations of the cement clinker burning process for training purposes are now possible. The interactive, flexible and extendable simulator was connected to the process control system of cement plants. In the future a suitable parameterisation of the model will make a simulation of special training scenarios, e.g. of the plant start-up or the blockage of a cyclone stage, possible.
Moreover the above mentioned steps for reducing the algebraic loops should be stepwise reversed. Consistent initial starting-values should then be achieved with the aid of continuation methods starting with a known trivial initial state of the system. With extending and detailing the model the simulator might help gaining a deeper understanding of the whole process.

ACKNOWLEDGEMENT
Thanks to R. Ostkamp from Krupp Polysius for actively supporting the process interface implementation.

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BIOGRAPHY

Henning Klein studied mechanical engineering at the University of Siegen. Since October 1999 he is working with Verein Deutscher Zementwerke e. V. (VDZ, Düsseldorf) in the department of Joint Environmental Issues. As a member of the organisation's research institute (Forschungsinstitut der Zementindustrie (FIZ)) Mr. Klein is examining the behaviour of mercury (Hg) with means of modelling and simulation.